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AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

STRUCTURES NOTE 473

AERONAUTICAL RESEARCH LABORATORIES STRUCTURES DIVISION ANNUAL REPORT 1979-80

EDITOR

F.H. HOOKE

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Structures Note 473

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DIVISION ANNUAL REPORT 1979 - 80

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ERRATA

Page 10 line 10, heading should read "Auto Valve Balance (AVB) System".

Page 10 line 14, "servo values" should read "servo valves".

Page 10 line 15, "on the value," should read "on the valve,"

Page 30 line 16, P.J. Sherman should read D.J. Sherman.

Page 31 line 12, G.W. Reville should read G.W. Revill.

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SUMMARY

This report describes the functions, organisation, staffing, unclassified research activities and ad-hoc investigations in progress in the Structures Division, Aeronautical Research Laboratories during the year 1979/80.

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16. ABSTRACT:

This report describes the functions, organisation, staffing, unclassified research activities and ad-hoc investigations in progress in the Structures Division, Aeronautical Research Laboratories during the year 1979/80.

1. TERMS OF REFERENCE

The functions of the Aeronautical Research Laboratories are:

To undertake research and development work on specific defence projects.

To act as consultants and make investigations for the Services and government departments or industries engaged on defence work.

To act as consultants and make investigations for other bodies on matters which call for the special facilities or skills of ARL.

To carry out such background research as is required for the proper execution of the above functions or as is of significance to the defence requirements of Australia.

2. FOREWORD

The Structures Division, headed by Dr. F.H. Hooke, is one of five scientific divisions of the Aeronautical Research Laboratories which are themselves part of the Defence Science and Technology Organisation.

The primary functions of Structures Division are to carry out background research and advise the Armed Services with regard to: (a) assessing the response of aircraft structures to externally applied forces and environments, and (b) ensuring that aircraft can be operated with a high degree of structural safety and reliability. In fulfilling these functions the work of the Division includes the following activities:

(i) Structural analysis related to both specific aircraft problems and background research on advanced methods of stress analysis and the applications of solid mechanics.

(ii) Research into the dynamics of structures, in particular the aeroelastic characteristics of both fixed and rotary wing aircraft.

(iii) Investigation of the response of aircraft to gust and manoeuvre loads both during special flights and in regular service, to determine the relationship between loads and strains in critical areas.

(iv) The development and application of mathematical models for structural reliability and fatigue life prediction particularly with regard to extending the life-of-type of military aircraft.

(v) Research into lethality of weapons and vulnerability of structures, together with studies of crashworthiness.

(vi) Experimental investigations into the static strength and fatigue characteristics of materials, components and full scale structures.

(vii) The development of advanced instrumentation for flight loads measurement, recording and analysis; and specialised testing equipment and control systems for the conduct of complex strength and vibration tests on materials, components and structures.

In addition, the Division's activities include investigation of aircraft accidents, atmospheric turbulence research and research involving thermal effects in structures.

Much of the work of Structures Division involves a close inter-relation between theoretical analysis, experimental research and the application of these to specific problems experienced by the Services. There are major facilities for the full-scale static and fatigue testing of aircraft structures; a specialised laboratory complex for the fatigue testing of materials and components; a mechanical testing laboratory with the largest universal static testing machine in Australia; a vibration and aeroelasticity laboratory; an electronic instrumentation laboratory and a flight instrumentation laboratory.

On past experience it is expected that both the scope and extent of this work could increase substantially in the forseeable future with the inclusion of such studies as the aeroelastic characteristics of helicopter rotors, full-scale structural tests on sections of a Minehunter, static and fatigue testing associated with the development of a new RAAF trainer, vibration testing of naval vessels, shock testing and shock isolation of heavy military equipment, analysis and testing associated with the life evaluation and life testing of RAAF aircraft, crash-dynamics research, the strength or dynamic behaviour of combat-damaged and repaired structural components and research into the behaviour of structures of fibre composite material. All experimental investigations are supported by basic and applied research in the various fields of activity.

3. GENERAL

3.1 Senior Staff Changes

Dr. A.O. Payne retired from the position of Senior Principal Research Scientist in charge of the Properties of Aircraft Structures Composite in June 1980. He joined the Structures and Materials Section of the Division of Aeronautics of C.S.I.R. in 1946, and became Senior Principal Research Scientist in 1975. He retired also from the position of Australian National Leader of T.T.C.P. Panel H3 on Fatigue of Aeronautical Vehicles, in which he is replaced by Mr. C.K. Rider.

3.2 Overseas Visits

Dr. F.H. Hooke visited Canada and the U.K. in November 1979 as Chief Coordinator of the Commonwealth Advisory Aeronautical Research Council, Field of Structures, holding discussions in Ottawa and then the main meeting of Coordinators at the Royal Aircraft Establishment, Farnborough, Hants. He later visited Avions Marcel Dassault in Paris and Flugzengwerk Emmen in Switzerland in relation to fatigue problems of the Mirage aircraft.

Mr. J.Y. Mann visited Switzerland, France and Israel in April/May 1980 to attend the Mirage Tripartite Meeting at Emmen to present methods developed at ARL for both restoring and improving the fatigue life of the Mirage main wing spar, and to discuss the evidence of fatigue cracking in the Mirage III structure in service.

Mr. C.K. Rider visited the U.S.A. during April, May and June 1980 as a Structures specialist scientist with the Final Evaluation and Negotiating Team of the R.A.A.F. for selection of their New Tactical Fighter.

3.3 International Agreements

Mr. B.C. Hoskin is Australian National Leader for T.T.C.P. Action Group HAG-5 on the Certification of Composite Aircraft Structures i.e., the airworthiness certification of aircraft structures which contain significant amounts of advanced composite materials such as carbon fibre reinforced plastic (CFRP). Both the announced candidates for the new Australian fighter procurement, namely, the F-16 and the F-18, use CFRP for major components. During the year he made two overseas visits; the first being in September 1979, at the Naval Air Development Centre, Warminster, USA. Following this meeting, Mr. Hoskin visited several US establishments to discuss aircraft structural applications of composite materials. The second meeting of HAG-5 was at Defence Research Establishment Pacific, Esquimalt, Canada, in February 1980 and, after this, Mr. Hoskin travelled to the UK to discuss British work on composite materials. At its two meetings to date, HAG-5 has identified key technical areas needing concentrated attention and is now in the process of evaluating work programmes aimed at resolving existing uncertainties in these areas.

Messrs. J.L. Kepert and K.C. Watters participated in the seventh meeting of TTCP Technical Panel WTP-1 on Terminal Effects of Weapons held in Melbourne in September 1979. They presented focus officer reports on the topics of Target Vulnerability and Survivability, and Lethality Assessment. The meeting decided to reorganise the Panel by appointing separate focus officers for land, air and marine targets; previously only a single focus officer was employed. Within Australia, reorganisation in conformity with this decision has been completed and this is expected to result in a more efficient organisational structure.

4. STRUCTURAL MECHANICS RESEARCH

Work in structural mechanics is primarily concerned with the determination of the stresses and deformations in aircraft structures; such information is necessary when considering the static

strength or the fatigue life of an aircraft. The main areas of current activity are the finite element methods of structural analysis, fracture mechanics and structures made of composite materials.

4.1 Finite Element Methods

Virtually all aircraft structural analysis is now carried out using general purpose structural analysis computer programs based on the finite element method. During the last year steps were taken to acquire a large such program to replace the relatively small in-house program, DISMAL, which has been used for the past decade. It is expected that the new program will be operational on the ARL computer by the end of 1980. Acquisition of this program will greatly extend ARL's capability in the structural mechanics area, both for research and for applied tasks. The program also has an extensive dynamic capability which will permit more detailed theoretical studies of vibration problems than has previously been possible. At the same time, the existing program, DISMAL, has been improved by the addition of a graphics package which was developed in-house.

4.2 Fracture Mechanics

Fracture mechanics is concerned with the behaviour of structures containing cracks or similar flaws; when an aircraft develops a crack in service a decision must be made on whether the aircraft can safely continue operating and fracture mechanics provides a basis for such a decision. A key parameter in fracture mechanics is the stress intensity factor. Finite element methods for determining the stress intensity factor have been previously developed at A.R.L. During the past year these were applied to two problems. The first was in connection with cracked gun barrels, the work here primarily being done by staff of the Materials Research Laboratories under guidance from ARL: results obtained using the ARL method agreed well with experimental results. The second application was in a study of fatigue in Canberra aircraft; again, predictions made by the ARL method agreed well with results obtained by other procedures.

4.3 Composite Materials

Composite materials, such as carbon fibre reinforced plastic (CFRP), are being increasingly used in aircraft structures in place of metals; use of CFRP can lead to substantial savings in structural weight, a consideration which is always of great importance.

In connection with Australian participation in TTCP Action Group HAG-5 (see earlier) reviews have been made of what are considered to be key technical areas for aircraft applications of composite materials. One of the areas identified is the structural performance of damaged composite structure and the associated question

of suitable repairs. In the past year a "crack-tip element" has been developed to permit the finite element analysis of cracked composite laminates, along with an "adhesive element" for use in the study of bonded laminates. Both of these elements have been used in a theoretical investigation of the repair of CFRP laminates containing either cracks or holes by bonding on scab patches. From results to date, it appears that the best repair for a cracked laminate is a composite patch with all fibres running transverse to the crack, however, for the repair of a hole, either an isotropic boron patch or a titanium patch appears to have equal merit.

An application of the use of fibre composite material for the repair of cracked structure is described below under "Mirage".

5. VULNERABILITY AND LETHALITY

Theoretical and applied studies into aspects of vulnerability continued throughout the year. A major theoretical study concerned the vulnerability of structural panels to closely spaced fragment impacts. This task arose from the need to formulate more accurate aircraft structural vulnerability models in order to assess the effectiveness of surface-to-air missiles fitted with focussed blast fragmenting warheads. A finite element model to deal with this situation has been developed and implemented on the computer, but is still to be applied to practical situations.

A major applied study that was undertaken concerned the vulnerability of surface warships to 500 lb (227 kg) bombs. Little information is available on this topic and it was necessary to formulate new "kill" definitions appropriate to modern combat technology. These replaced the old and rather unsatisfactory definitions used during World War II.

Active support for other TTCP activities has been maintained and, as mentioned in an earlier section, reports on Target Vulnerability and Survivability, and on Lethality Assessment were presented at the meeting of Technical Panel W-1 held during the year.

6. VIBRATION AND AEROELASTICITY

An aspect of research which has been studied for some years is that of vibration testing of aircraft structures. Traditionally this has been done by using a number of vibration exciters attached to the structure. These were individually adjusted on an iterative basis to excite each natural mode of vibration prior to detailed measurement. The process requires a skilled and experienced operator and some modes can be difficult to isolate satisfactorily.

A new method of testing was first proposed by ARL in the early 1960's and demonstrated to be effective on simple structures. This relied on a numerical procedure to optimise the force distributions. Since then the method has been little used because of difficulties experienced in acquiring large quantities of vibration data in a reasonably short space of time. Recent digital equipment acquisitions have now permitted this technique to be re-evaluated on full scale aircraft structures with considerable success. Fast Fourier Transform techniques are used to process transfer function data which have been measured by a repetitive series of frequency sweeps. These data are then used to predict the required force distributions to excite natural modes of vibration. Tests have been carried out on two widely different aircraft types and good correlation achieved between the predicted and measured force distributions.

7. FATIGUE RESEARCH

Low Cycle Fatigue of Engines

(a) Co-operation with DARPA (USA) and Pratt and Whitney.

As a result of a number of TF30 engine failures in the USAF, some of which resulted in the loss of the aircraft, the RAAF became increasingly concerned regarding the possibility of Low-Cycle Fatigue (LCF) failures in the TF30-P-3 engines installed in its F111-C fleet.

ARL were requested to act as consultants to the RAAF on LCF and to provide support in the acquisition of data and its application in assessing the safe lives of LCF-prone engine components, and this became particularly urgent as Pratt and Whitney Aircraft (PWA), the manufacturers of the TF-30, downgraded the lives of many components to below the usual overhaul interval of 1000 hours.

In response, ARL set up a joint working party comprising Mechanical Engineering, Materials, and Structures Divisions. Two task plans were approved, one (DST 79/084) seeking to develop life prediction methods, the other (AIR 79/083) aimed at gaining confidence in the procedures used by PWA for LCF life estimation of TF30 engine components. These activities are now incorporated into a project arrangement between the US Defence Advanced Research Agency and the Australian DSTO which was signed on 29 August 1980.

The collaborative project, which aims to establish a 'retirement-for-cause' (RFC) lifing procedure for selected engine components, will be conducted in four phases.

Phase 1. Prediction of safe life based on a crack initiation criterion (which is the current PWA procedure.)

Phase 2. Prediction of crack propagation life.

Phase 3. Verification of retirement-for-cause philosophy and formulation of an inspection plan.

Phase 4. Trial implementation of the RFC philosophy on the selected components in at least two RAAF TF30 engines.

Structures Division's contribution to this programme involves the acquisition of a high-temperature fatigue test machine (a specification has been written and tenders offered - the machine is to be purchased with DARPA funds,) tests at room and elevated temperature to determine lives to crack initiation, similar tests for crack growth lives, life predictions, reliability analysis, thermal modelling (perhaps), and assistance with stress analysis.

One aspect of the TF30 Component Improvement Programme, operated by the U.S. and to which the RAAF contributes, is the possibility of Australian industrial participation. Under this arrangement PWA have approached ARL to make a life analysis of two components, a low pressure compressor stub shaft and a high pressure turbine coupling shaft. An ARL proposal has been sent to PWA.

Structures Division will contribute to the analysis by assembling materials properties and LCF data, carrying out life estimations, and, if necessary, applying fracture mechanics principles to utilize crack growth life.

(b) Co-operation with the U.K. (NGTE)

In November 1979 the U.K. suggested that they and ARL might co-operate on some areas of engine LCF including usage, component life prediction and retirement-for-cause. Draft agreements have been exchanged and they include the ARL view that any cooperative arrangement should concentrate on information exchange in the areas covered by the DARPA/DSTO agreement.

8. ATMOSPHERIC TURBULENCE

ARL has been asked by the RAAF to provide a model of the atmospheric gust environment encountered by Australian aircraft. As a first stage in this task a survey of the various reports relevant to the Australian environment has been prepared. The result is a bibliography which gives a comprehensive coverage of measurements of atmospheric turbulence in Australia, of related climatological studies and of Australian work on the response of aircraft to gusts. From these reports, those which give actual aircraft measurements of

turbulence occurrences at different heights have been selected and their results reanalysed to compare them with the Royal Aeronautical Society Design Code (ESDU Data item 69023). Figure 1 shows how the distance between 10 ft/sec gusts varies with altitude. The ESDU design curves are shown, and each of the various aircraft measurements is shown as a point surrounded by an octagon whose area is proportional to the distance flown by the aircraft in the corresponding altitude band. Although the data is not sufficient to define a curve on its own, it is compatible with the ESDU data item except in the high altitude (above 30,000 ft) band where the observed measurements are generally more severe than would be expected for aircraft equipped with storm-avoidance radar. A greater severity of turbulence at these levels may be expected because of the strength of the Australian jet stream and the amount of flying done in its vicinity.

9. EXPERIMENTAL TECHNIQUES: INSTRUMENT DEVELOPMENT

9.1 AFDAS (Aircraft Fatigue Data Analysis System)

Pleasing progress has taken place in the acceptance of the strain range pair counting concept by the RAAF for fatigue monitoring. In service evaluation trials of a prototype counter have begun with an installation in a Mirage aircraft at the RAAF Base Williamtown and a second system is scheduled for tests in a Butterworth Mirage. It is anticipated that successful evaluation will be followed by the installation of AFDAS in a range of RAAF aircraft, with a possibility of inclusion in each aircraft of the NTF.

9.2 AFTRAS

The design of an airborne flight trials recording and analysis system (AFTRAS) for ARDU has been completed and the flight recording system is currently undergoing evaluation trials prior to use in F111C trials. The Quick Look data analysis system has been extensively used by ARDU for a number of RAAF flight trials with a marked improvement in the early availability of test data.

9.3 TERCOM

Assistance in instrumentation development has been provided to Systems Division in the trials of the Terrain Computer Mapping (TERCOM) equipment installed in an Army land-rover.

9.4 Manifold Block for Hydraulic Valves

Manufacture of the manifolded block for the miniature valve packs has been completed and assembly is now proceeding in preparation for their use in the CT4 Fatigue Test rig.

The Department of Productivity is conducting a patent search with the view of taking out a patent on this item of equipment.

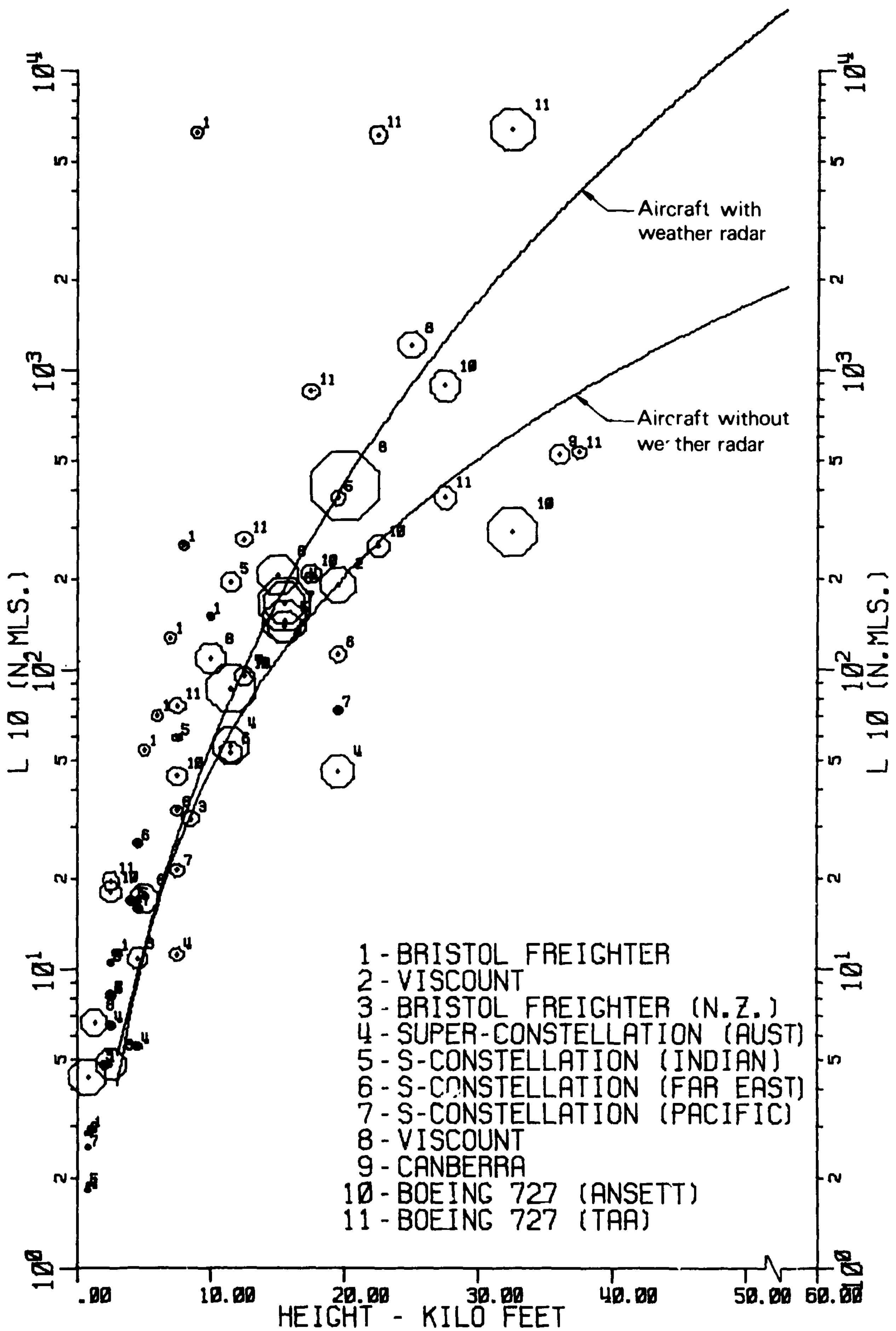


FIG. 1 AVERAGE SPACING OF 10 F.P.S. GUSTS VS ALTITUDE

9.5 Multi-Channel Fatigue Test Controller

The year 1979-80 has seen considerable effort devoted to the development of a state of the art multi-channel fatigue test controller for the CT-4 Air Trainer fatigue test. This controller represents a major advance on previous systems in that it is designed for fully automatic operation and takes full advantage of recent developments in microprocessor technology. The task has required the development of a number of unique sub systems and of these the following are most worthy of note:-

Auto Value Balance (AVB) System

This is a microprocessor controlled, auto-zero facility which periodically samples and re-balances control loop offsets in all load-controlling servo channels. This procedure eliminates the null offset effects of the servo values caused by oil leakage, thermal effects on the value, and shock effects. It ensures all control loops are working to achieve null in the shortest possible time with the greatest possible accuracy, throughout the period of the test.

Auto Roll Compensation (ARL) System

In this sub system load control and displacement control have been combined. The displacement control loop is placed around the load control loop and the combination acts to keep the altitude of the floating structure stable about the roll axis. Stability is achieved without loss of accuracy of load control and without the need for additional servo channels.

Load Interaction Decoupling

Side loading channels and vertical loading channels on the undercarriage are tightly coupled. Without compensation this tight coupling would necessitate very slow loading rates to minimize interaction loads. By providing electronics cross coupling through suitable networks, it has been possible to increase the loading rate by a factor of 2, while maintaining interaction at a negligible level.

Push-Pull Loading Mechanism

In a fatigue test control system the news channels are major cost items and every effort is made to reduce the number required for a particular application. A novel loading mechanism (Fig. 2) has been developed which allows a single servo channel to control both positive and negative 'g' loads, through appropriate whiffle trees, as they are applied to the upper and lower surfaces of a wing. This mechanism, which is the mechanical analogue of an electronic class AB push-pull amplifier, not only halves the number of servo channels required but also eliminates interaction between upper and lower surface loading. The mechanism imposes no accuracy or speed-of-loading penalty.

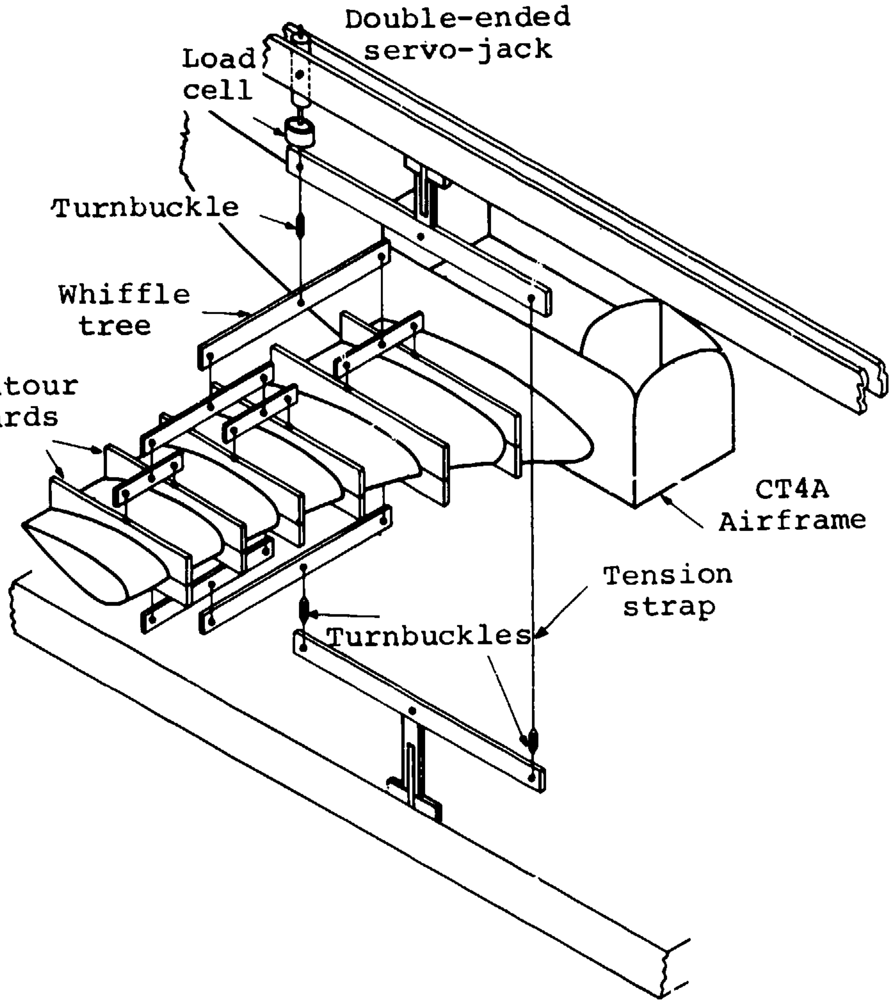


FIG. 2 PUSH-PULL LOADING MECHANISM CT4 FATIGUE TEST

Real Time Log Decrement Display

During the year the Real Time Logarithmic Decrement Display Unit was completed (Fig. 3). It was demonstrated during the ARL Open Day exhibition and raised considerable interest among visitors. This fully portable unit displays on an oscilloscope, in real time, the damping characteristic of a structure subjected to random noise excitation. It employs a 16 list microprocessor to "average" the incoming signals and suitable analogue-to-digital equipment is included. An appropriate companion random noise source for excitation of the structure has also been developed. Further units based upon this ARL development are being constructed at G.A.F.

10. CRASH SAFETY AND AIRWORTHINESS

10.1 Crash Safety

The Crash Safety programme was initiated by the Department responsible for Civil Aviation (the Department of Civil Aviation now merged into the Department of Transport) and activity on this programme has continued. The main effort has been in the correlation of ARL experimental investigations with a large project at NASA, Langley Field. Correspondence has been exchanged and the information gained will assist in the completion of our report.

10.2 Weathering of Helmets

Testing to determine the effect of weathering on crash helmets manufactured from different materials, including moulded thermoplastics has proceeded. Three stages of testing have been completed (before exposure and after 6 and 12 months exposure) and no deterioration has been detected yet.

10.3 Investigations for RAAF

Projects undertaken for the RAAF include (i) a study of the crashworthiness of a modified seat for the Iroquois helicopter and comparison with the standard seat, (in conjunction with a comfort assessment by the Cybernetics Group), (ii) the functioning of a safety harness buckle and an apparent inadvertent release was investigated, (iii) crashworthy design principles and criteria for a basic Training Aircraft are being reviewed and recommendations are being prepared.

11. ACCIDENT INVESTIGATIONS

The Division has been involved in several accident investigations being conducted by D.O.T. resulting in the following experiments being undertaken:

RANDOM – DEC COMPUTER

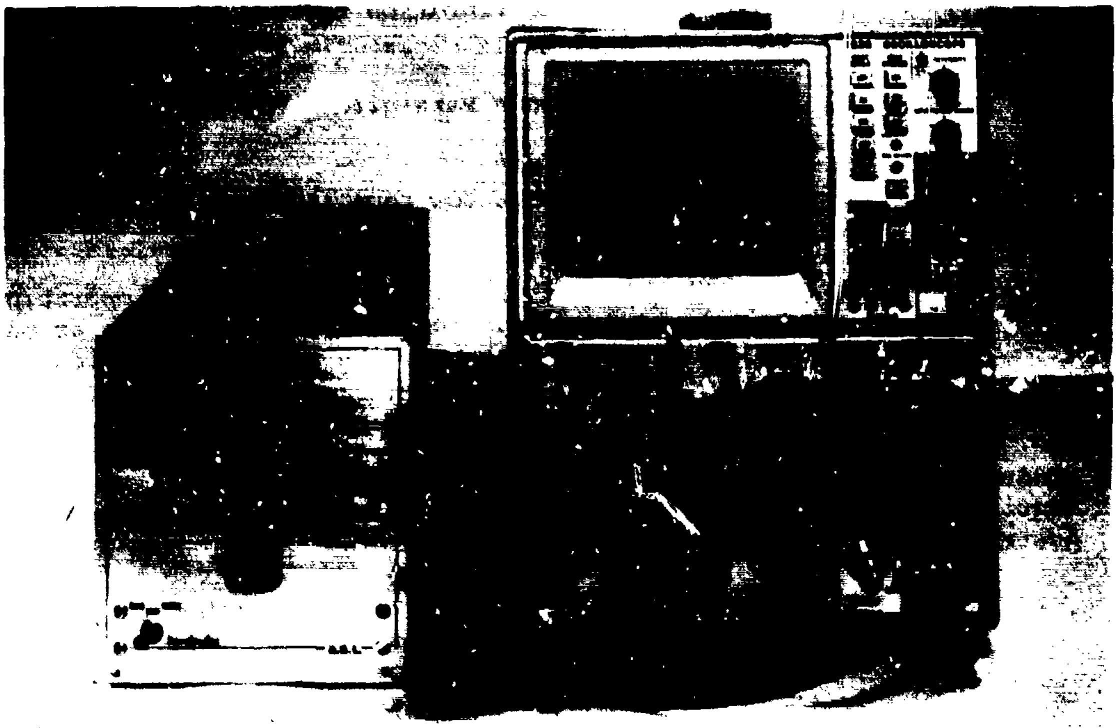


FIG. 3(a) REAL-TIME PROCESSING OF A RANDOM-DEC SIGNATURE

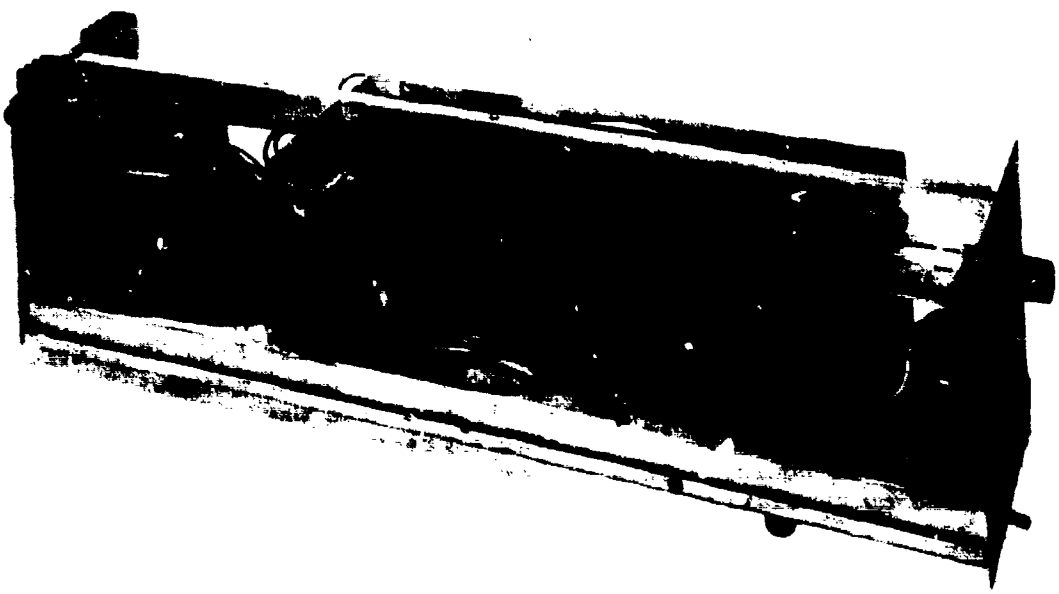


FIG. 3(b) UNIT WITH COVER REMOVED

a) Proof loading and vibration testing of a Piper PA-32 stabilator.

b) Strength tests on a Para-glider tow rope and fittings.

c) Strength tests on a tow rope involved in a Glider accident.

d) Determination of glider release mechanism operating forces under various towing angles and loads as part of the investigation into the accident referred to in (c).

The investigation in (d) has led to a general survey being conducted by Structures Division for D.O.T. into the operating forces required of all the tow-plane and glider release mechanisms used in Australia.

e) The strength of a glider tailplane sandwich skin (fibre glass and foam) was experimentally investigated. This was fairly complex because of the multiple component materials and layer orientations.

12. SPECIFIC TASKS

12.1 Mirage

During the year a major investigation has been concerned with extending the service life of the Mirage aircraft. The investigation was given urgency by the discovery late in 1979 of cracks in the rear flange bolt holes of the Mirage main spar in the RAAF wing sent to F+W for the continuation of a full-scale fatigue test, and, soon after, the confirmation of cracks in the Mirage wing being used by ARL for a strain survey study and in a spar removed from a crashed Mirage wing. Refurbishment studies of the rear flange bolt holes will be described below. Other areas of investigation have included the effect of wing-assembly on stress distribution in the main spar and panel and analysis of the full scale fatigue tests to predict service safe life.

12.1.1 Safe lives based on full-scale test failures

Fatigue tests at ARL and at the Swiss Federal Aircraft Factory caused failures at similar locations in the main wing spar, but at different test lives. The ARL test life was seven times the Swiss test life (with each test life expressed in terms of its respective test hours). This difference could not initially be reconciled by cumulative fatigue damage theory using strain data

available at the time. In June 1979 further strain data from another wing were recorded by the Swiss at the commencement of their second test. Making the assumption that these data represent the strains which were applied during the first Swiss test, it has been shown that the different lives given by this and the ARL test are in fact compatible with cumulative damage theory.

The severity of the tests has been related to that of RAAF service conditions using flight strain measurements and fatigue meter records. This has provided estimates of mean and safe lives in RAAF service based jointly on the two test results. These safe lives apply to the region of the main spar which failed in the two tests. It has been shown that recent (1977-80) RAAF flying is considerably more severe than at the time of the ARL test (1973).

12.1.2 Reliability analysis for the rear flange bolt holes

In view of the time needed to implement the refurbishment, and the fact that the most severely cracked wings will not be refurbished, the RAAF have requested that ARL investigate the risk of operating, on a safety-by-inspection basis, the unrefurbished wings with cracks in the rear flange bolt holes.

Using structural reliability analysis methods developed by ARL, an estimate will be made of the risk of failure with specified inspection schedules. Input data for the analysis is being assembled. Crack growth data is obtained from service NDI results and from specimen tests of ARL, and the latter have also provided data on residual strength in the presence of fatigue cracks. A spectrum of local stress exceedence has been obtained from the RAAF fatigue meter data in conjunction with strain data recorded in flight and on the Swiss fatigue test article.

12.1.3 Fatigue life extension by refurbishment

In September 1979 the discovery of significant cracking in bolt holes of the spar of the RAAF test wing being tested in Switzerland at a fatigue life much earlier than anticipated, and indications of cracks at identical locations in a large number of wings of RAAF fleet aircraft caused immediate concern regarding the safety of the Mirage fleet and the ability of the aircraft to meet its required life of type. It also introduced an urgent need to develop methods for both restoring and extending the fatigue lives of cracked wings.

This task was undertaken within Structures Division and a comprehensive series of fatigue tests was commenced, using large specimens of a size and geometry closely representing the critical section of the spar. The development of a refurbishment scheme was based upon a "standard" test specimen (Fig. 4) designed

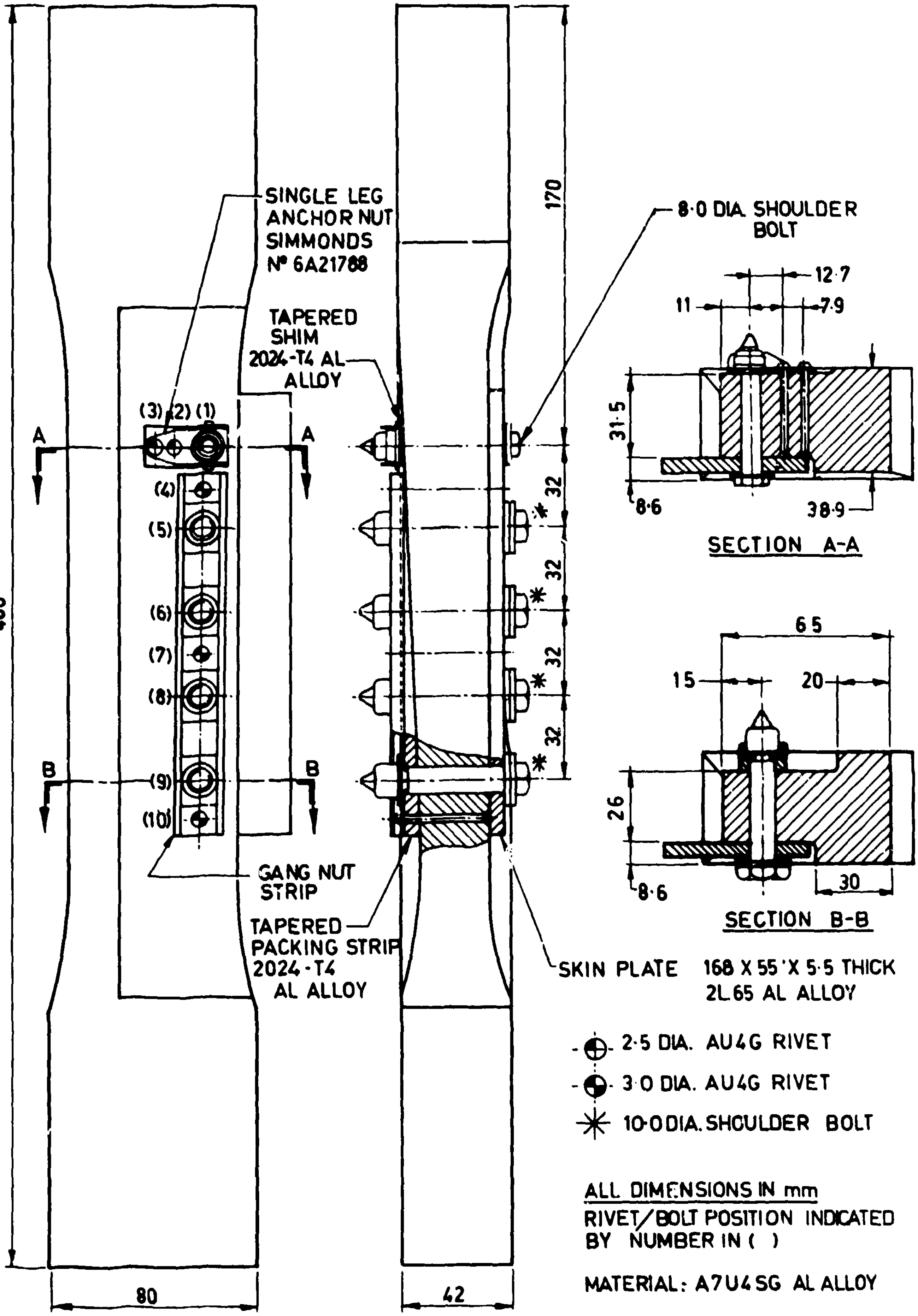


FIG. 4 MIRAGE SPAR LOWER REAR FLANGE FATIGUE SPECIMEN

directly from the drawings of the spar. Subsequent detailed examination of spars from cracked aircraft and wings at the Commonwealth Aircraft Corporation indicated a number of serious discrepancies between the drawings and actual spars at the critical section, and these required that certain aspects of the refurbishment be investigated in much greater detail than was originally anticipated.

In developing a method for extending the fatigue life of the relevant parts of the wing spar it was considered highly desirable to remove completely any pre-existing fatigue cracks. Thus a basic requirement was to enlarge the diameters of the bolt and rivet holes in the spar for the purpose of either removing cracks or to clean up and accurately size the holes for a subsequent operation. Various refurbishment options were investigated, including:-

(a) oversize reamed bolt holes, utilizing close-fit belts,

(b) interference-fit steel bushed bolt holes using standard bolts,

(c) cold-expanded bolt holes (using the Boeing split-sleeve process),

(d) oversize reamed and/or cold-expanded rivet holes,

(e) modified anchor-nut assemblies (used in conjunction with, in particular, options (b) and (d)).

All fatigue tests were carried out under a load sequence derived from the Swiss Mirage test spectrum. Of the 70 specimens tested by June 1980 about 10 were refurbished at fatigue lives of between about 25% and 50% of their estimated failing lives. In addition to assessing the relative fatigue performances of various options, valuable information has been obtained regarding fatigue crack propagation rates and the residual static strength of fatigue-cracked specimens.

The major conclusions which have been drawn from the results to date are as follows:

a progressive reduction in fatigue life results from progressively larger reaming as in option (a).

- option (b) can provide a significant increase in fatigue life compared with holes of the same external diameter fitted with close-fit bolts.

- option (c) provides some improvement in life compared with oversize reaming, but introduces other problems because of rivet holes in close proximity and small edge distances,

- the use of close-fit rivets in rivet holes results in a longer fatigue life than in the case of unfilled rivet holes,

- reduced pitches between bolt holes and rivet holes oriented in a chordwise direction result in a reduction in fatigue life and introduce difficulties in applying a standard refurbishment scheme.

In summary, the research has shown thus far that useful improvements in fatigue life are possible by combinations of cold-expanding rivet holes and the fitment to bolt holes of interference-fit steel bushes providing hole pitches are adequate. In cases where the pitch of holes is less than specified on the drawings, the standard refurbishment scheme may be necessary to ensure that the improvements in fatigue life can be maintained.

The techniques developed at ARL have been applied to the RAAF wing under test in Switzerland and have been adopted by the RAAF for the refurbishment of wings at the Commonwealth Aircraft Corporation.

12.1.4 Comparison ARL and F+W fatigue test sequences

In an investigation of the effect of specific machining defects on fatigue life a series of fatigue tests was conducted on small specimens incorporating the blind-anchor nut hole detail at which the Australian test wing failed. The tests were conducted under the two loading sequences as were applied respectively in the Australian and Swiss full scale fatigue tests. For the basic Australian test the equivalent 7.8 g stress was 155 MPa, whereas for the basic Swiss spectrum the equivalent 7.5 g stress was 223 MPa. The Swiss spectrum was thus clearly more severe, but nevertheless three specimens endured for an average life of 6.5 X 10^4 flights, or over 10 times the full scale test life. Other tests were then carried out with the stress spectra scaled by factors of 1.4, 1.8, 2.0, 2.2, 2.4 and 2.6.

Because of the long testing time, no comparative results were obtained for the two spectra, tested at a scaling factor of unity (the basic test series.)

Results of the tests are plotted in Fig. 5. These results showed that the ratio of lives under the two spectra was critically sensitive to stress scaling factor, varying from about 1.5 at a scaling factor of 1.4 to about 12 at a scaling factor of 2.2. No explanation has yet been found for the divergence between small specimen results and the full scale test results.

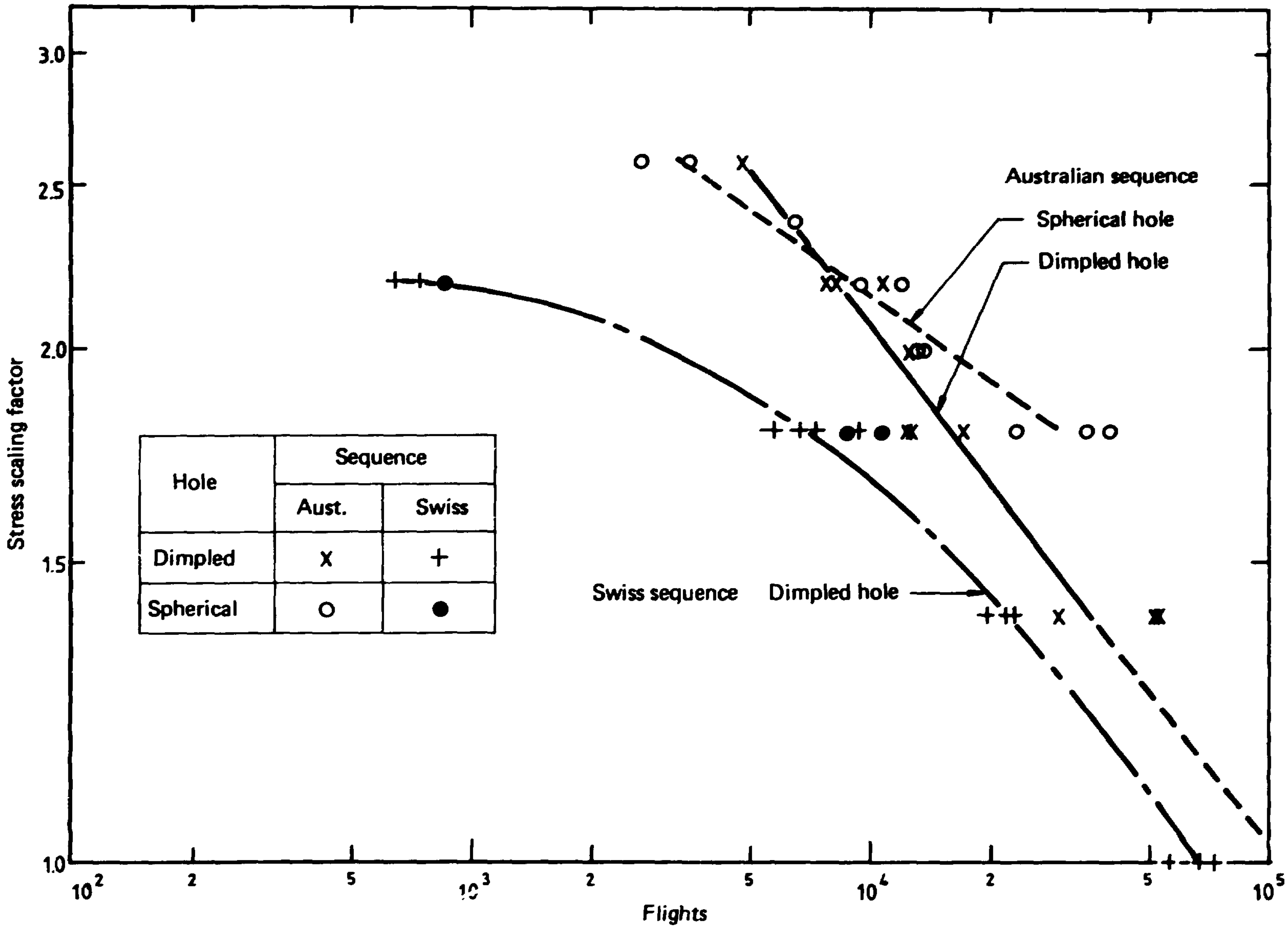


FIG. 5 FATIGUE TESTS UNDER ARL AND F+W LOAD SEQUENCES USING SMALL SPECIMENS, VARIOUS STRESS SCALING FACTORS

12.1.5 Fibre composite patch repair

A report has been completed on the design of boron fibre reinforced patches for the repair of cracked wing skins in Australian Mirage aircraft.

The design studies of repair patches were confirmed by a fatigue test programme whose original aim was to verify with experimental evidence that a boron patch repair scheme would prevent further crack growth at the fuel drain hole in the lower wing skin.

Test lives ranging from 36 to 122 equivalent aircraft flight years have been obtained from a total of seven specimens.

The experimental program is a joint effort with Materials Division and has enabled non-destructive inspection techniques to be developed for establishing when the crack is growing under the patch. Bonding techniques have also been improved giving rise to the long periods of crack retardation.

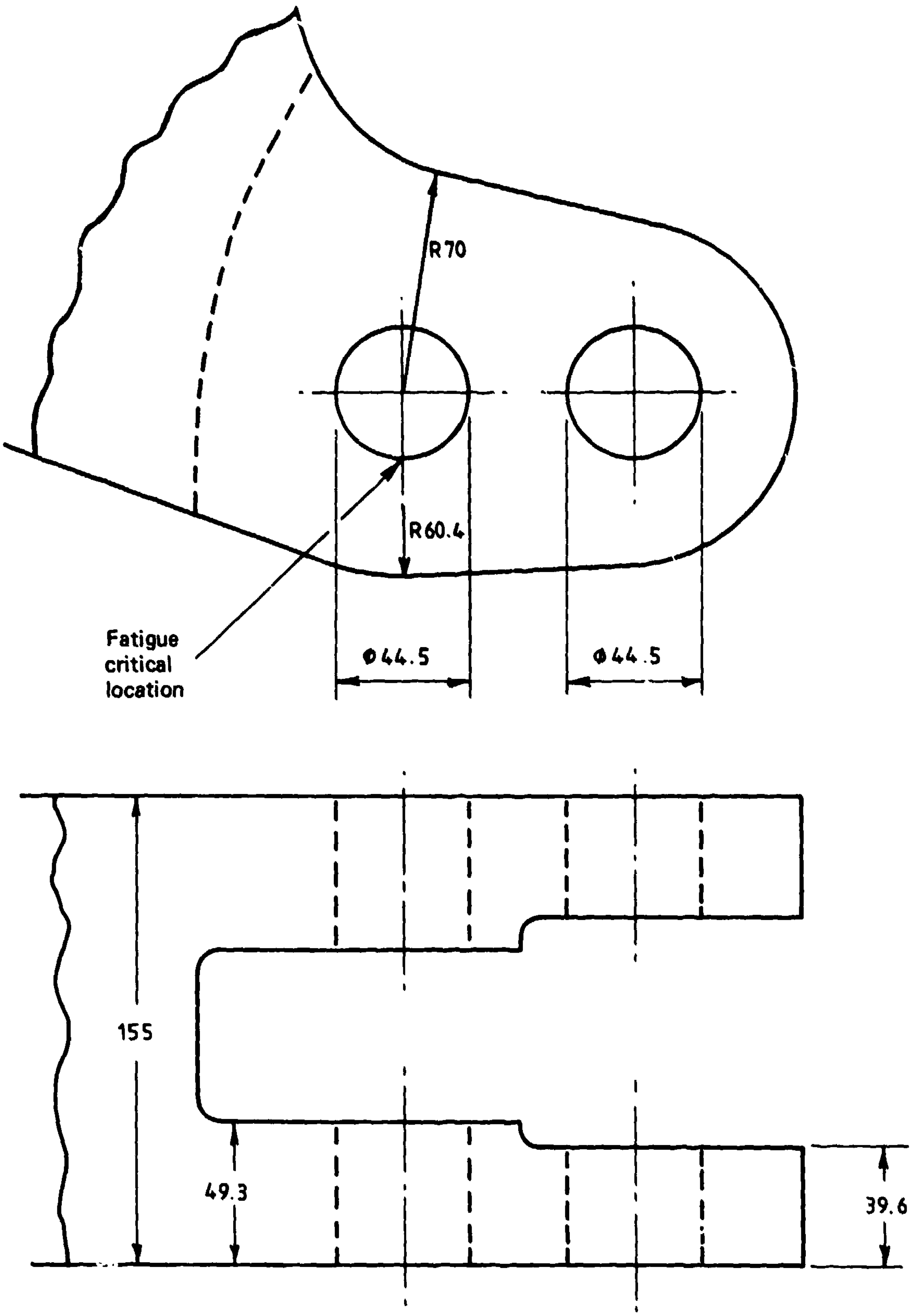
Ground loadings on a Mirage have been performed at Avalon Aerodrome to survey the strains in the main spar region of the wing for the purpose of (a) providing data for fatigue life calculations, and (b) to assess the effect of boron fibre composite patches on the distribution of stress in the adjacent skin and in the main spar.

12.2 Canberra Lower Centre Section Lug Fatigue

Since the early sixties Canberra aircraft of the RAAF have been operating on a safe life basis making use of fatigue meter data in conjunction with a damage assessment formula for the inner bolt hole of the lower centre section forging lug, Fig. 6. This item was shown to be fatigue critical on a full scale fatigue test carried out by the manufacturer (The English Electric Co. Ltd.) in 1957, Fig. 7.

The damage assessment formula was originally developed at ARL in 1961 but has since been updated by the RAAF to account for changes in mission and stores loadings. Since many of these aircraft have now reached (and in some cases even exceeded) their calculated safe lives, ARL has been asked to investigate the feasibility of operating them on a safety-by-inspection basis with a view to reaching their desired life-of-type, which is currently 1984.

Initial calculations showed an extremely shallow critical crack depth. Had such cracks been found in service, immediate and permanent grounding would have resulted. Detailed revisions of the applied loadings were therefore made. These revisions involved the



Scale : Approx half full size

All dimensions in mm

FIG. 6 CANBERRA LOWER CENTRE SECTION FORGING LUG

FIG. 7 FAILED CANBERRA LOWER CENTRE SECTION LUG FROM ENGLISH ELECTRIC FATIGUE TEST

Air Force Office in Canberra, who have relatively direct access to British Aerospace at Warton, where the Canberra was designed. The detailed stressing data thus obtained showed that loads originally assumed had been too high by up to 25%, a magnitude which, in circumstances involving fatigue, can completely change a situation.

So it is with the Canberra lug. The revised calculations have shown that the critical fatigue crack size is actually well above the threshold of detection, and that the rate of growth of a subcritical fatigue crack under the action of service loadings is satisfactorily low. This means that crack growth monitoring in service is feasible, and it has been tentatively shown that inspection intervals acceptable to both the operator and the requirements of safety have resulted. Thus, it appears likely that the desired life of type will be realisable on the basis of safety by inspection.

It must be noted that the particular fatigue critical location considered above is but one of two such locations: another on the same lug has yet to be examined.

12.3 CT4A Air Trainer Fatigue Investigation

12.3.1 Flight trials

A major part of the input to the CT4 Fatigue Test depends upon knowledge of the frequency and magnitude of the loads on various parts of the structure. The flight trials on the CT4 were set up with the aim of determining

1. the loading distribution over the wings, fuselage, fin and the tail plane during normal flying,

2. the frequency of applied loads during normal training missions.

Aircraft A19-031 was instrumented with 40 strain gauges and 28 other transducers measuring aircraft parameters such as accelerations, angular accelerations, control surface positions and engine parameters. All these data were recorded onto a magnetic tape recorder situated in the aircraft next to the pilot. The basic format was digital multiplexing at 3600 data/second.

The first flight of the present series was flown at the RAAF Base at Edinburgh in April 1980 and, up to August 1980, 39 flights have been flown. The majority of the flights (30) were simulated training missions and the rest were flights to investigate parts of the flight envelope which were of special concern.

As an aid in the quick verification of the data and diagnosis of faults the ARL Quick Look Facility (a small minicomputer with magnetic tape and graphics facilities) was transported to RAAF Base Edinburgh. This facility enabled the data to be checked as soon as the aircraft landed and a turn-around time of approximately 2 hours was achieved. As a result there was very little loss of data caused by equipment malfunctions.

The whole trial program was arranged in 3 sections each lasting 3 weeks. The time between each section was used for more complete analysis on the ARL PDP-10 computer to determine the suitability of the data.

During the period April to August the weather was not conducive to air turbulence so that the flights requiring turbulent input are still to be made. However all other flights in the flight schedule were completed satisfactorily.

Work is proceeding on the analysis (approximately 5.5 million data) and should be completed by the end of 1980. One of the main methods to be used is principal component analysis into uncorrelated time histories of independent modes of response.

12.3.2 CT4 Airframe

During the year the fatigue test programme has advanced with design of the test rig, most of the manufacturing having been completed. Rig assembly is proceeding along with construction and commissioning of the fluid power control system components.

12.3.3 Ground calibration loadings

One CT4 Airtrainer aircraft has undergone the third ground calibration at ARL as part of the programme to determine load/strain relationships for various parts of the structure. These relationships are to be applied in evaluating flight test data and the resulting information regarding flight loads will in due course be used in a fatigue test of a complete airframe. A view of the aircraft readied in the laboratory for calibration is shown in Fig. 8.

The general plan of the fatigue test is that the flight test recording of strain readings will be translated into loads and expanded into a control tape for the DEC 11/44 computer used to control the test. Because it relates loads to strains the ground calibration is an important step in this sequence. However time has allowed just a limited dimension of loadings so that extensive finite element analyses are being used to help interpret and extend these experimental results, especially those related to load transfer at the wing root. Fig. 9 indicates the mesh now in use.

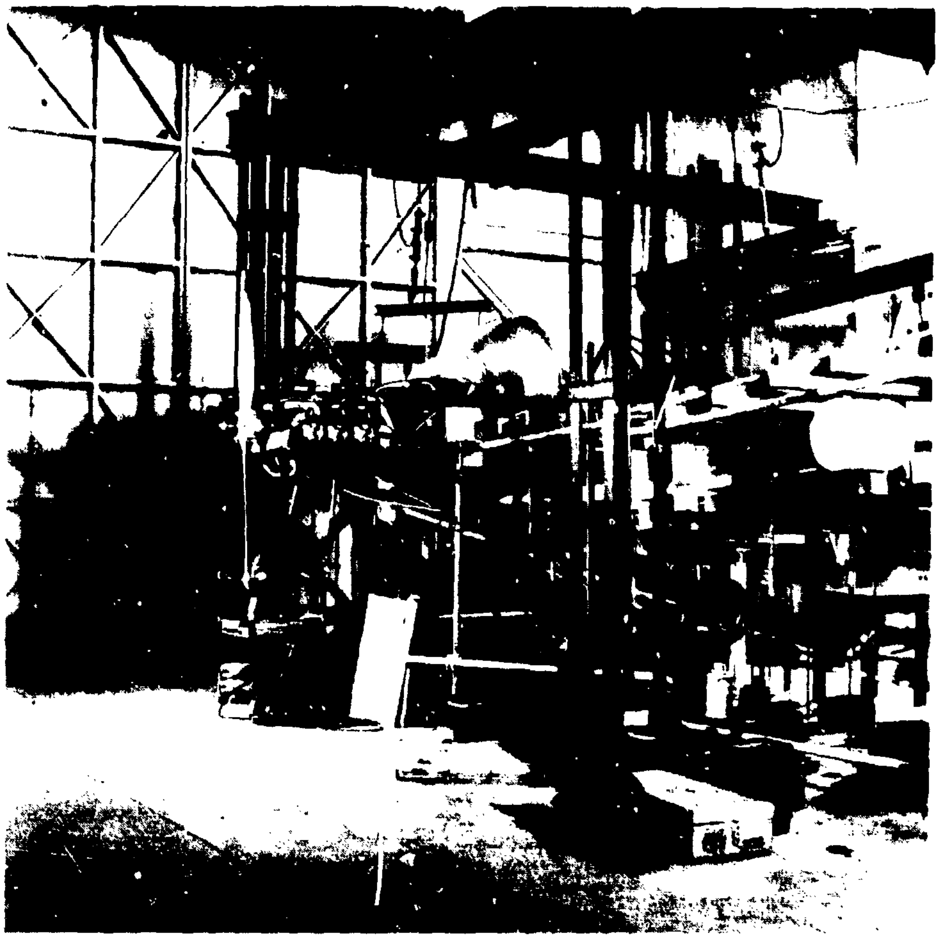


FIG. 8 CT4 AIRCRAFT RIGGED FOR GROUND STRAIN EVALUATION

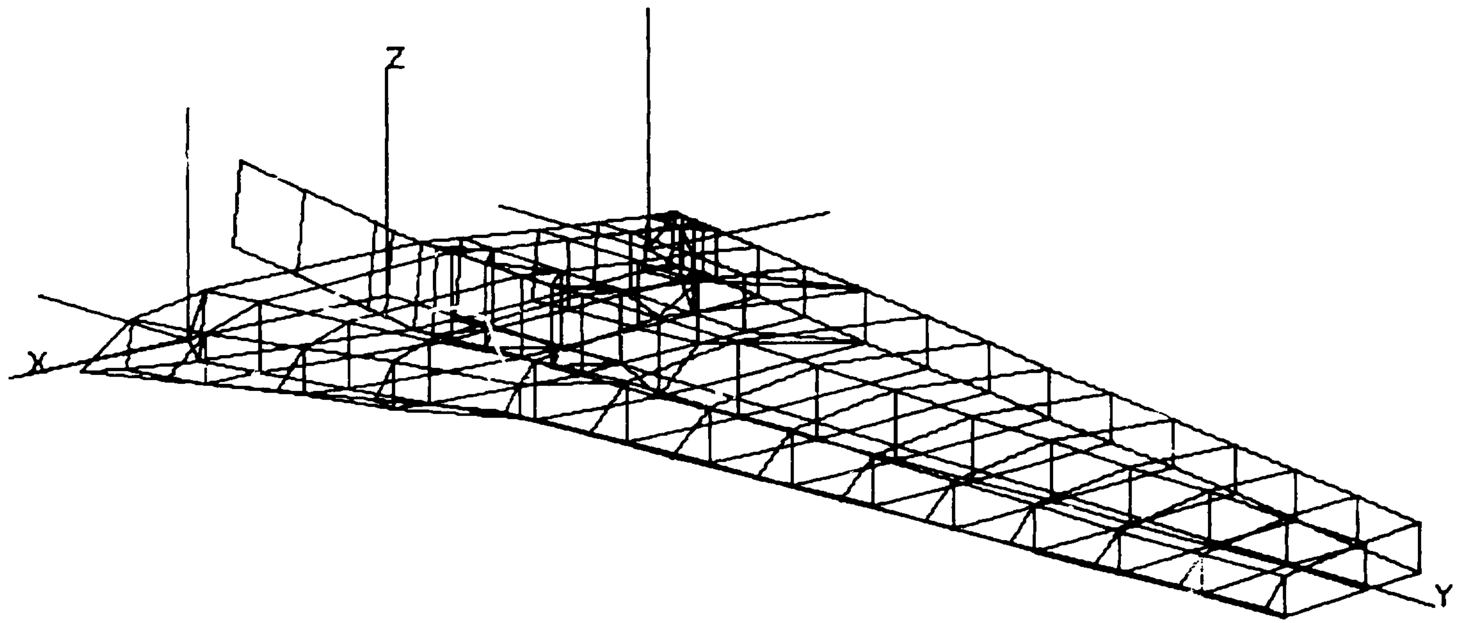


FIG. 9 CT4A WING F.E. MODEL

The capacity of the DEC 11/44 will allow on-line data reduction from the test. In addition, the previously extensive computing load for real time control will be reduced by using a control procedure, optimised for minimum excursion time between load turning points.

12.4 Remotely Piloted Vehicles

At the request of the RAAF, ARL, in conjunction with Weapon Systems Research Laboratories, has carried out a study of possible service applications of Remotely Piloted Vehicles (RPVs) and of the basic vehicle technology. In this connection, a review has been made of the structural design principles for RPVs; also a preliminary design study has been performed of a typical RPV concept (Fig. 10).

12.5 F111C

A brief study was carried out on the effect of cracks in the crew module of an F111C.

12.6 Helicopter Tie-Down Loads

At the request of the Directorate of Naval Aircraft Engineering, a theoretical investigation was made of the load experienced by a helicopter which is tied down on the flight deck of a naval vessel. The point at issue was the structural integrity of the tie-down fittings of the helicopter when the vessel is operating in storm-sea conditions.

12.7 New Tactical Fighter

The new tactical fighter to replace the Mirage during the 1980's is currently to be chosen between the F-16 and F/A-18 aircraft. A representative from Structures Division was included in the Final Evaluation and Negotiating Team (FEANT) which visited the USA from April to June 1980. His task was to examine the basis on which the service life of the airframes could be expected to consist of 6000 hours of maintenance-free operation, and also to examine the status of programmes to demonstrate flutter-free carriage of external stores to the design envelope.

12.8 Macchi Spar Booms

A report is being prepared in which the results of fatigue tests conducted on 18 centre section spar booms from Macchi aircraft are presented along with the major conclusions reached. This work has enabled the spars to remain in service until fatigue cracks have reached a certain length, thus permitting a much longer service life for the aircraft before replacement of these items.

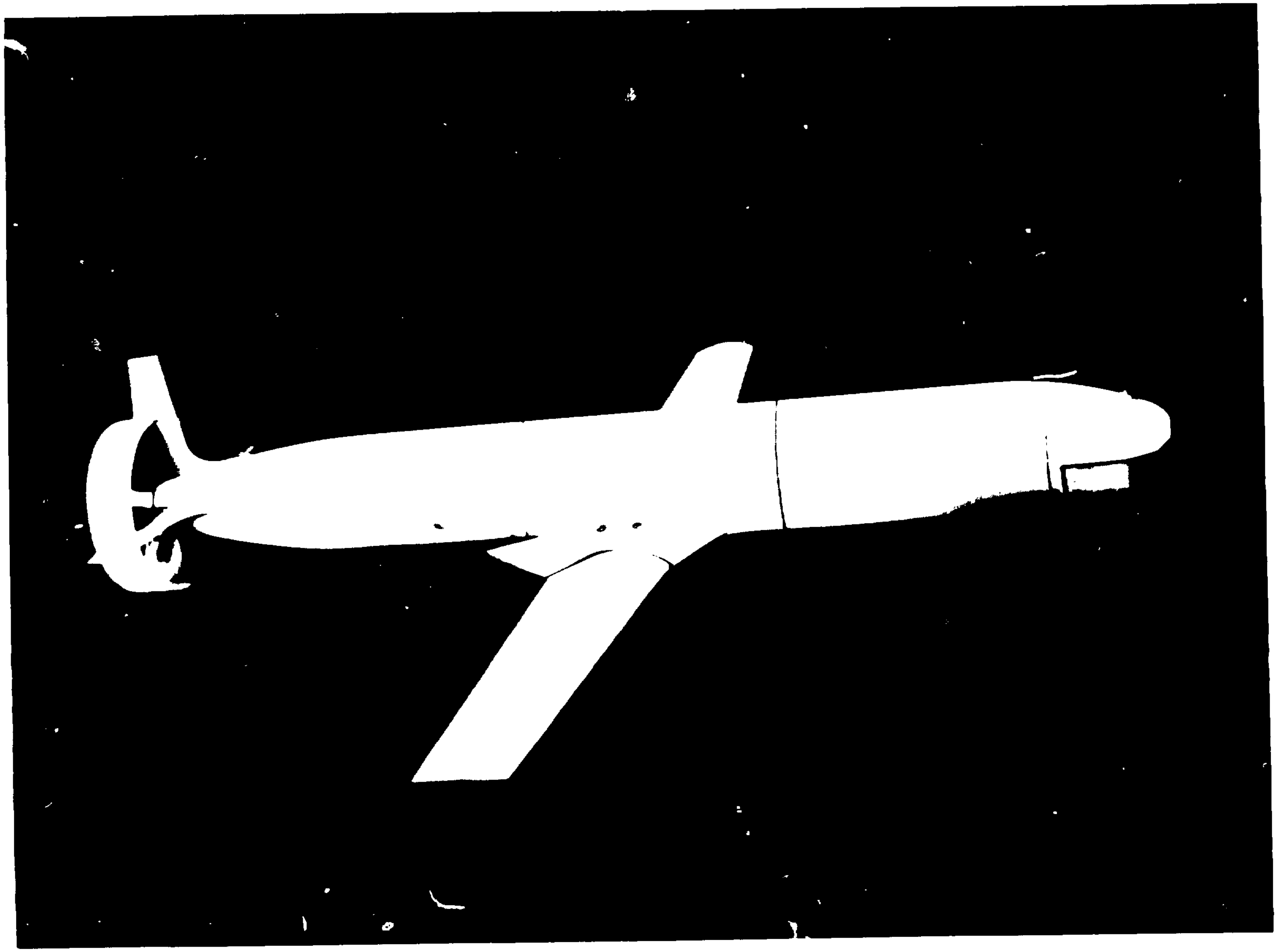


FIG. 10 A PROPOSAL FOR AN RPV DESIGN

12.9 Minehunter

The Navy Minehunter material development programme has continued with the addition of a four-point bending fatigue investigation of beams manufactured by M.R.L. They are constructed using a sandwich of GRP outer layers and a PVC rigid foam core material as proposed for the vessel's hull and superstructure.

A section of Minehunter structure in the form of a typical keel/bulkhead joint is being prepared for a dry-dock-keel-load test.

Two more creep machines are being installed which will enable six specimens to be tested simultaneously since more data on the creep properties of specimens made of various thicknesses of GRP and loaded to the same stress level are required.

13. PROFESSIONAL STAFF AT 30.6.80

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Programmer Class 6
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17. ORGANISATION OF STRUCTURES DIVISION

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(Vacant)

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